COMPUTATION OF SOLAR RADIATION HEAT GAIN IN ANALYSING ENERGY EFFICIENT OPERATION OF AN AIR-CONDITIONING SYSTEM

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ABSTRACT

In any building, air-conditioning system is essential to maintain thermal comfort of the occupants as well as ensuring their optimum productivity. However, the electricity consumption by air-conditioning alone is more than 50% from the total electricity consumption. Hence it must be designed carefully to optimize electrical energy supplied and avoid energy wastage. The operation of an air-conditioning system are depend largely on the heat gain absorbed by the building. Heat gain may come from internal heat gain as well as external heat gain but the main contribution of heat gain is the solar radiation heat gain.Solar radiation heat gain values varies every day with respect to the different position of the sun.In order to solve energy wastage problem in air-conditioning system, the computation of the solar radiation heat gain is done. In this study the equations used are the 'Clear-sky Solar Radiation' as suggested by ASHRAE in book of fundamentals 2009. The equations are then being made acomputer model of C++ computer programming by using Code::Blocks version 8.02 to calculate the solar radiation heat gain.The heat gain of every months are represented by the heat gain on their 21st day. The results are then being plotted into graphs to show the relationship between Irradiance, E and Total Solar Radiation Heat Gain, Q to a building. Lastly, the total solar radiation heat gain curves for twelve months are being plotted in another graphs for ease of analysis on how the sun position can actually affect the solar radiation heat gain.

ABSTRAK

Dalam setiap bangunan, sistem penghawa dingin merupakan salah satu keperluan asas untuk menjamin keselesaan penghuninya serta memastikan produktiviti kerja berada pada tahap tertinggi. Namun begitu, sistem penghawa dingin menggunakan tenaga elektrik lebih daripada 50% daripada jumlah keseluruhan penggunaan tenaga elektrik. Oleh sebab itu, sistem penghawa dingin perlu direka bentuk secara teliti untuk mengelakkan pembaziran tenaga di samping menggunakannya secara optimum. Operasi setiap sistem penghawa dingin bergantung besar kepada kedapatan haba yang diserap oleh bangunan tersebut. Kedapatan haba adalah terdiri daripada kedapatan haba dalaman dan kedapatan haba luaran akan tetapi kedapatan haba radiasi solar merupakan penyebab utama. Kedapatan haba radiasi solar adalah berbeza-beza pada setiap hari malah berbeza juga pada setiap jam kesan daripada posisi matahari yang berbeza. Untuk menyelesaikan masalah kebaziran tenaga elektrik dalam penggunaan penghawa dingin, kedapatan haba solar radiasi perlu dikira secara teliti. Dalam pengkajian ini, persamaan-persamaan yang digunakan merupakan 'Kaedah Solar Radiasi Langit Cerah' seperti mana yang telah disarankan oleh ASHRAE di dalam Buku Asas 2009.Kemudiannya, persamaan-persamaan itu telah diprogramkan di dalam sebuah program komputer menggunakan perisian 'Code::Blocks' versi 8.02 untuk memudahkan pengiraan. Kedapatan haba pada setiap bulan diwakilkan oleh kedapatan haba oleh hari yang ke 21 pada setiap bulan. Keputusan dapatan haba telah dijadikan dalam bentuk graf untuk menunjukkan hubungkait antara sinaran matahari dan kedapatan haba solar radiasi oleh sesuatu bangunan. Akhir skali, keluk setiap jumlah kedapatan haba solar radiasi untuk jangka masa 12 bulan telah dijadikan sekali lagi dalam graf yang berlainan untuk memudahkan analisis tentang bagaimana posisi matahari boleh memberi kesan kepada kedapatan haba solar radiasi.

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LIST OF SYMBOLS

A	Area
ab	Air mass component
ad	Air mass component
β	Solar altitude angle
CO_2	Carbon dioxide
E_0	Extraterrestrial radiant flux
E_{SC}	Solar constant
E_b	Beam normal irradiance
E_d	Diffuse horizontal irradiance
E_t	Clear-sky irradiance
$E_{t,b}$	Beam/direct irradiance component
$E_{t,d}$	Diffuse irradiance component
$E_{t,r}$	Ground reflected irradiance component
H	Hour angle
I_t	Hourly global solar radiation
m	Air mass
n	Number of day
ϕ	Solar azimuth angle
θ	Angle of incidence
Q	Total fenestration solar radiation heat gain
q_b	Beam solar radiation heat gain
q_d	Diffuse solar radiation heat gain
δ	Solar inclination
τ_b	Beam solar optical depth
τ_d	Diffuse solar optical depth
Ψ	Surface azimuth
γ	Surface solar azimuth angle

LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
AST	Apparent solar time
BLAST	Building load analysis and system thermodynamics
CL	Cooling load
ET	Equation of time
HVAC	Heating, ventilation and air-conditioning
IAC (θ,Ω)	Direct indoor solar attenuation coefficient
IAC_D	Diffuse indoor solar attenuation coefficient
LON	Longitude of site
LSM	Longitude of local standard time meridian
LST	Local standard time
SHG	Solar heat gain
SHGC (θ)	Direct solar heat gain coefficient
$(SHGC)_D$	Diffuse solar heat gain coefficient
UMP	Universiti Malaysia Pahang
UTC	Universal time coordinated

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Nowadays, due to economic and environmental reasons many organizations around the globe are constantly under pressure to reduce the energy consumption in their building operation. Energy cost is one of the main cost drivers in any businesses and the reduction in energy consumption will lead to reduction of operating costs and thereby helps to increase the organization's profit.

Besides the depletion of natural resources, the main environmental issue which relates to the energy consumption is the increase of emission of carbon dioxide (CO_2) that contributes to global warming. As a result, the idea of green technology and efficient energy usage has been introduced and improved to minimize the problem from arising.

In any building, air-conditioning system is regarded as essential equipment for ensuring the comfort of the building's occupants so that they can carry out their activities in a comfortable environment. In addition, air-conditioning is among appliances that consume most electricity, hence it must be carefully designed to optimize the electrical energy supplied.

To initiate the proper energy usage for air-conditioning, the Malaysian government has introduced several steps in order to educate the community regarding energy efficiency in daily life. One such initiative done since 2011 is by implementing an order to all government offices to set the air-conditioning temperature no lower than

24 ºC and this order will be extended to the private sector by 2013. Furthermore, a rebate of RM 200 and RM 100 are given to people who buy 5-Star Energy Rating refrigerators and air- conditioning equipment respectively. These initiatives are among the initiatives for Malaysia to achieve its vision to reduce carbon emission by 40% in 2020.

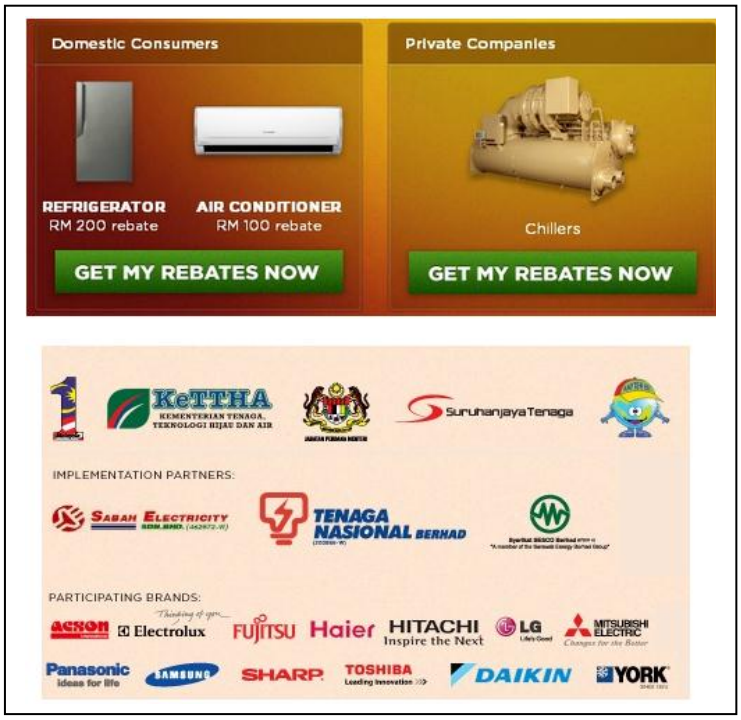

Figure 1.1: Rebate promotions for refrigerator and air-conditioning

Source: www.saveenergy.gov.my (2011)

Figure 1.2:5-Starenergy efficient tag logo

Source: www.tnb.com.my (2013)

As part of the engineer's responsibility to help achieve this vision, the installation of an air-conditioning system must properly take into count the heat gains into the building which comes from external and internal means. The major heat gains for external means comes from the radiation of sunlight through the windows .To ensure an air- conditioning energy efficient building, the heat gain need to be calculated properly.

1.2 PROBLEM STATEMENT

The air-conditioning system is one of major appliances in any building nowadays. In most modern air-conditioned office and commercial buildings in Malaysia, air conditioning systems take up to 60 to 70% of the total electricity consumption every month and often the cooling load actually required is less compared to the cooling load supplied by the air- conditioning system. This will therefore cool the room more than what it is required and result in electrical energy wastage. Furthermore, the current method of heat gains of solar radiation calculation which has big contribution for the total heat gain is not thorough and detailed.

This project will cover the computation of variable heat gain into a building. The heat gain computation will cover only the external source especially the solar radiation through the windows. On the other hand, the internal heat gains such as heat from occupants, appliances and lighting are not being calculated because these values do not vary with time in a day.

1.3 PROJECT OBJECTIVES

The objectives of this project are determined. There are three objectives that have been defined to be focused on as stated below:

i. To understand the knowledge of solar radiation that varies with the sun position

ii. To compute heat gain into hypothetical building by means of solar radiation

iii. To establish a computer model to compute variable heat gain for assessing the real- time loads for air-conditioning.

1.4 SCOPE OF STUDY

The project objectives are narrowed down to reduce the complexity of the study. Firstly, a comprehensive literature review has been conducted properly to determine suitable formulas for the heat load calculations for solar radiation which varies with the sun position.

Secondly, the office of Faculty of Mechanical Engineering is proposed as the hypothetical building to be used in this project. The hypothetical building here is that the analysis does not take the office information as a whole together with the number of occupants, appliances and lighting but will take only the building envelope information especially window specifications. This is to synchronize with the objectives of the study in which it is only covers the solar radiation through windows.

CHAPTER 2

LITERATURE REVIEW

2.1 POTENTIAL OF SOLAR ENERGY IN MALAYSIA

Mohd Zainal et al (2010) has stated that energy has become a fundamental part of people's daily lives as well as being vital to the social and economic progress of every country. They also explained that the energy that are being using today can be divided into two groups called the renewable and non-renewable energy. As the name goes, renewable energy is derived from natural processes that are replenished constantly. One of the various forms of renewable energy is the solar energy which is derived directly from the sun. Moreover, they also stating some statistics back from 2005 which shown that the worldwide electricity generation was 17450 TWh out of which 40% originated from coal, 20% from gas, 16% from nuclear, 16% hydro, 7% from oil and the remaining of nearly 2% that makes up electricity from renewable sources. For the same year in Malaysia, the percentage of energy profile in Malaysia is mainly comes from natural gas for both national commercial primary and national power sector categories.

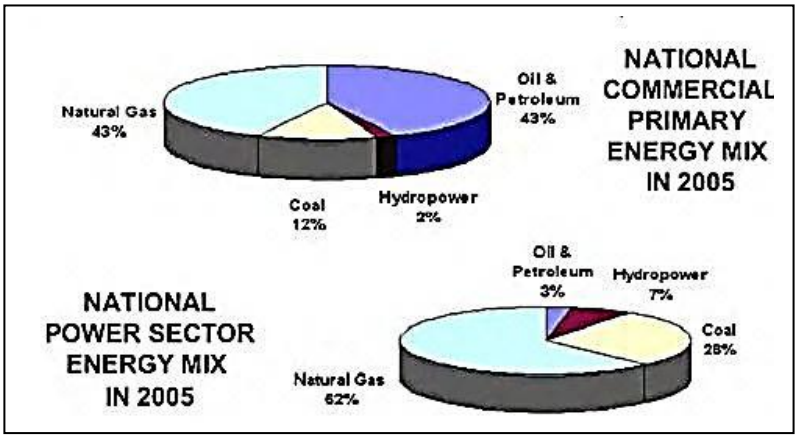

Figure 2.1: Energy profile in Malaysia

Source: TNB Research (2005)

Later, they also elaborated on the impact of the increasing usage of the energy. According to them, they major issues of the world nowadays are none other than energy problem and global warming. Global warming is a phenomenon that occurs due to the increase in the average temperature of the earth resulting from the toxic gases produced by factories and burning of fossil fuel around the world. In order to reduce this effect, alternative energy source must be used. They ended their explanation by stating that renewable energy sources such as solar and wind energy have been used for quite some time but there are still many reasons why they have not emerged as primary energy sources.

Kamaruzzaman et al (1992) as cited in a journal entitled 'Monthly mean hourly global solar radiation estimation' has stressed that for the studies of solar energy, the data on solar radiation and its component values at a given specific location are very crucial and important. This is to gather accurate knowledge of the availability of solar resource at any place. Furthermore, they also mentioned that the average values of hourly, daily and monthly global irradiations on horizontal surfaces are needed in many applications of solar energy design.

2.2 MALAYSIA SOLAR IRRADIANCE

As cited in the same journal, Muzathik et al (2010) has relates the solar energy with Malaysia perspective and he has come up with a view by stating that Malaysia is a country which is blessed by having abundant of solar energy. The annual average solar irradiations for Malaysia has a magnitude of 4.21- 5.56 kW h m^{-2} and the sunshine duration is more than 2200 h per year. But as for many developing countries like Malaysia, solar radiation measurements are not easily been achieved due to high equipment costs, maintenance and calibration of the measuring devices. So, the alternative solution for this problem is to estimate solar radiation by using modeling approach such as the prediction of hourly global solar radiation, I_t for any day.

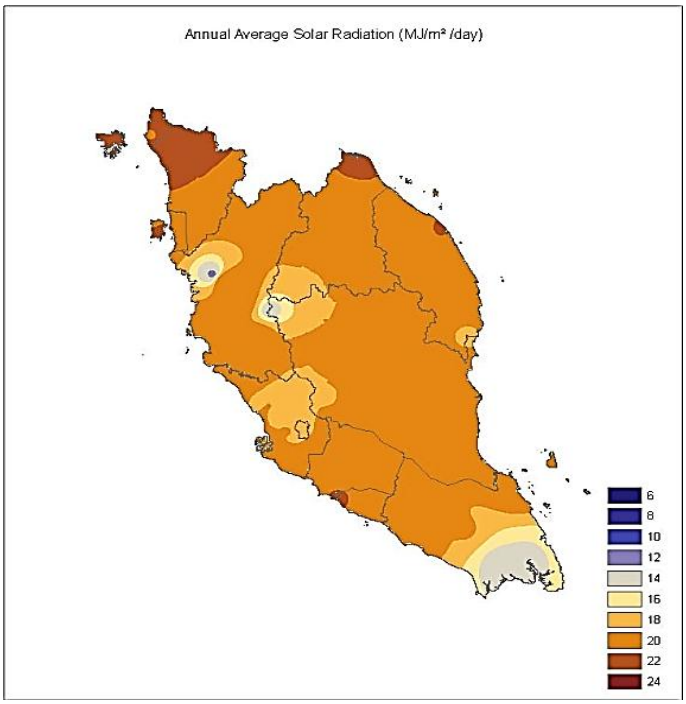

Figure 2.2: Annual average solar radiation in Malaysia

Source: TNB Research (2005)

2.3 AIR-CONDITIONING ENERGY CONSUMPTION

Nina et al (2012) has stated that tropical climates countries such as Malaysia, Singapore, Thailand and Indonesia are very concern about cooling in building for the occupant's comfort. Although thermal comfort is a major concern but the energy consumption in building especially for air-conditioning system must be taken into count. They have also mentioned that most of all commercial offices in Malaysia which are being occupied by air conditioning system consume averagely 70 percent of the total energy consumption in a year. Thus, a precise and accurate cooling load calculation should be applied for the essential decisions regarding the required capacity of the air conditioning system.

In an another study done by Al-Rabghi et al (2004), they has mentioned that the percentage of energy consumed by air-conditioning systems in buildings in city of Jeddah, Saudi Arabia during summer is over 50 percent of the total electric consumption. According to them, energy is utilized in sizeable quantities to provide air-conditioning in offices, commercial buildings, educational institutions and homes. Resulted from that, they has suggested a need to study alternative means of air-conditioning and to identify and implement strategies to save energy and at the same time maintaining good thermal comfort environment in the buildings.

2.4 HEAT GAIN AND COOLING LOAD CALCULATION PRINCIPLES

According to ASHRAE (2011), heating and cooling load calculations are the primary design basis for most heating and air-conditioning systems and components. Cooling and heating load calculations can significantly affect first cost of building construction, comfort and productivity of occupants and operating cost of energy consumption. In general, heating and cooling loads are the rates of energy input(heating) or removal (cooling) required maintaining an indoor environment at a desired temperature and humidity condition.

Heating and air conditioning systems are designed, sized, and controlled to accomplish that energy transfer. The amount of heating or cooling required at any

particular time varies widely and depending on external and internal factors. Peak design of heating and cooling load calculations are used to determine the maximum rate of heating and cooling energy transfer needed at any point in time.

In an air-conditioning design, the following heat flow rates, each of which varies with time must be differentiated.

- Space Heat Gain which is an instantaneous rate of heat gain is the rate at which heat enters into and/or is generated within a space. Heat gain is classified by its mode of entry into the space and whether it is sensible or latent.
- Entry modes include
    i. Solar radiation through transparent surfaces
    ii. Heat conduction through exterior walls and roofs

2.5 EXTERNAL HEAT GAINS

2.5.1 SOLAR RADIATION HEAT GAINS

Thevenard et al (2009) believed that solar heat gains (SHG) and the cooling load (CL) play a great part in the comfort conditions. They elaborated the idea by mentioning that cooling loads comprise both sensible and latent components and depending on the heat transfer by means of conduction, convection and long-wave radiation through the building envelope. Furthermore, a significant fraction of the cooling load is also being contributed by solar heat gains through fenestration and indirectly by the absorption of solar radiation through the envelope.

Apart from that, they also suggested that the design conditions data should take count for all 12 months of the year instead of on an annual basis. This is because the peak cooling design conditions happen not necessary during the hottest month but it may occur during the shoulder season when the sun is lower on the horizon and imposes larger solar heat gains through vertical fenestration. So, it is advisable by them to calculate the loads on a monthly basis and take the yearly maximum as the design value.

From another study done by Wu et al (2007), he suggested that the best solar radiation data at any place of interest should be measured continuously and accurately at that site for long term. However, it cannot be done because of certain problems such as the financial of the maintenance, instrument calibration and other limitations.

2.5.2 CLEAR-SKY SOLAR RADIATION

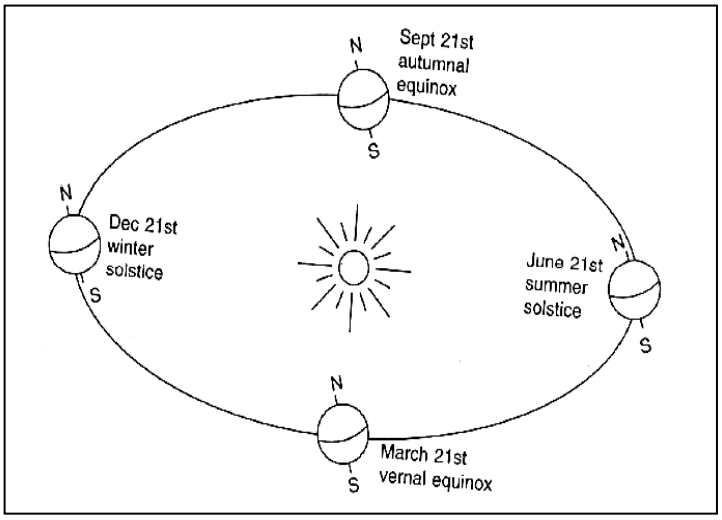

Figure 2.3: Motion of earth around the sun

Source: ASHRAE Book of Fundamentals (2009)

ASHRAE (2009) gives an overview regarding the clear-sky solar irradiance. According to it, clear-sky solar irradiance parameters are useful in calculating solar related air conditioning loads for any time of any day in a year. The parameters are provided for the 21st day of each month. This is because the 21st day of the month is usually a convenient day for solar calculations because June 21 and December 21 represent the solstices which is the longest and shortest days. Apart from that, March 21 and September 21 are close to equinox in which the days and nights have the same length of time.

From another study done by Al-Sanea et al (2004), they had stressed the importance of solar radiation by mentioning that the accurate estimation of solar radiation on the earth's surface is needed in many applications. The calculations include

the air conditioning loads in buildings, design and performance evaluation of passive building heating system as well as solar energy collection and conversion system.

In addition, from their exhaustive study, they found that ASHRAE clear- sky model appears to be a general method for them to calculate the temporal and spatial variations of solar radiations. Furthermore, they also stressed the users who wish to use this model for their calculations by reminding that as the name of 'clear-sky' implies this model only applicable to basic atmosphere only.

In addition, the statement is further explained by Thevenard et al (2009) by stressing that the calculation of solar heat gain by using ASHRAE solar radiation model should only concerned with solar radiation under clear skies because this will normally result in the maximum solar heat gains through fenestration.

2.6 INFLUENCE OF DIFFERENT OUTDOOR DESIGN CONDITIONS

According to Bulut et al (2008), outdoor design conditions such as local climatic conditions are important parameters for energy efficiency of buildings. This is because the energy consumption in a building depends on climatic conditions and the performance of heating, ventilating and air conditioning (HVAC) systems changes with them. In addition, a better design of a building HVAC application that takes amount of right climatic conditions will result in a better comfort and more energy efficient buildings. They added that outdoor design conditions are weather data information for design purposes showing the characteristic features of the climate at a particular location which will affect building loads and economical design. The result of incorrect selection of outdoor conditions can be dramatic in view of energy and comfort.

This theory is being supported by Schiavon et al (2008) which also suggested that the heating energy need is not affected by the air velocity increase but it depends on the outdoor conditions (climate zone).

2.7 ENERGY EFFICIENT BUILDING

2.7.1 STRATEGIES THAT REQUIRE NO EXPENDITURES

Al-Rabghi et al (2004) had explained on air-conditioning controller function which act as the brain of air-conditioning system. This controller will be fed with information such as indoor control parameters such as air temperature and relative humidity. Later, these value will be compared with set point values and if there is sufficient different, the controller will send signals to other components to act accordingly. They also stressed that if the controller does not function properly then the required indoor environment will not be achieved and may result in either or both of energy wastage and dissatisfaction of thermal comfort of occupants.

They also further elaborated their explanation by mentioning that large portion of energy would be wasted if the building is kept at low temperature during unoccupied periods. In order to solve this problem, they suggested that the air-conditioning controller must be frequently re-programmed to save energy during unoccupied periods. Furthermore, they also promoted regarding the sensors that are sensitive to the presence of occupants which already available in the market. These sensors can turn the air-conditioning off when the space is unoccupied.

2.7.2 STRATEGIES THAT REQUIRE FURTHER INVESTMENT

According to Al-Rabghi et al (2004), the best method for reducing the external loads of a building is to insulate the building thermally. They later explained that when a building is thermally insulated especially the external walls and the roof, the total load will reduce. Today, there are lot of insulation materials such as blocks, bricks and layers that available in the market for home builders. They also recommended that imposing effective rules and regulations is needed as to make sure that all new buildings are thermally well insulated. This suggestion can be a reality through good support from city municipality.

Besides, they also suggested that one way to minimize external solar radiation loads is by using double or triple glazing for windows. This is because among the external loads for a building is the infiltration load which is unwanted external air that enters into the building through small holes and openings. In order to minimize this load, they building should be air tight. Their arguments continue by mentioning that the cost of the insulation layers or the insulated construction materials for home owners can be paid back in a very short period of time as the electricity bill will be lower.

Besides, in the same journal they also suggested that energy simulation programs can be effectively used to study the energy consumption by a building even it is not being built yet. Different alternative cases and parameters can be considered and being studied in order to determine which is the most economical and energy efficient. They also elaborated on the energy simulations programs by giving out several programs that are already available in the market. Based on them, simulation programs are mainly two types which the first one is the commercial type.

This commercial type is developed by the air-conditioning companies such as TRACE which is developed by TRANE. On the other hand, the other type is the government supported programs such as BLAST and DOE 2. In these programs, building information together with the weather file for the city under study can be supplied to the program. Then the program will does it works by calculating the building loads, air-conditioning loads, plant loads and the energy demands and these calculations are performed on hourly basis. They ended their explanation by stating that although these programs are best used during the designing stages of buildings but one can still get benefit from these programs for studying and also modifying the existing buildings.

Thermal cool storage is a method of energy saving in a building (Al-Rabghi et al, 2004). It is known that the outdoor temperature changes from hour to hour and from month to month. This will later result in the different cooling load and air conditioning demand which varies during the day and throughout the year.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will be discussed on the methods of how this research should be conducted. In this study, there are few process stages that have been through. The processes will be described in the following flow chart together with their explanations. The methodology flow chart is constructed to show the process of tasks throughout the project and is it constructed based on the scope of the project so that all the objectives will be achieved at the end of the project. Besides, the flow chart also acts as a guideline to make sure that the project is on the right track.

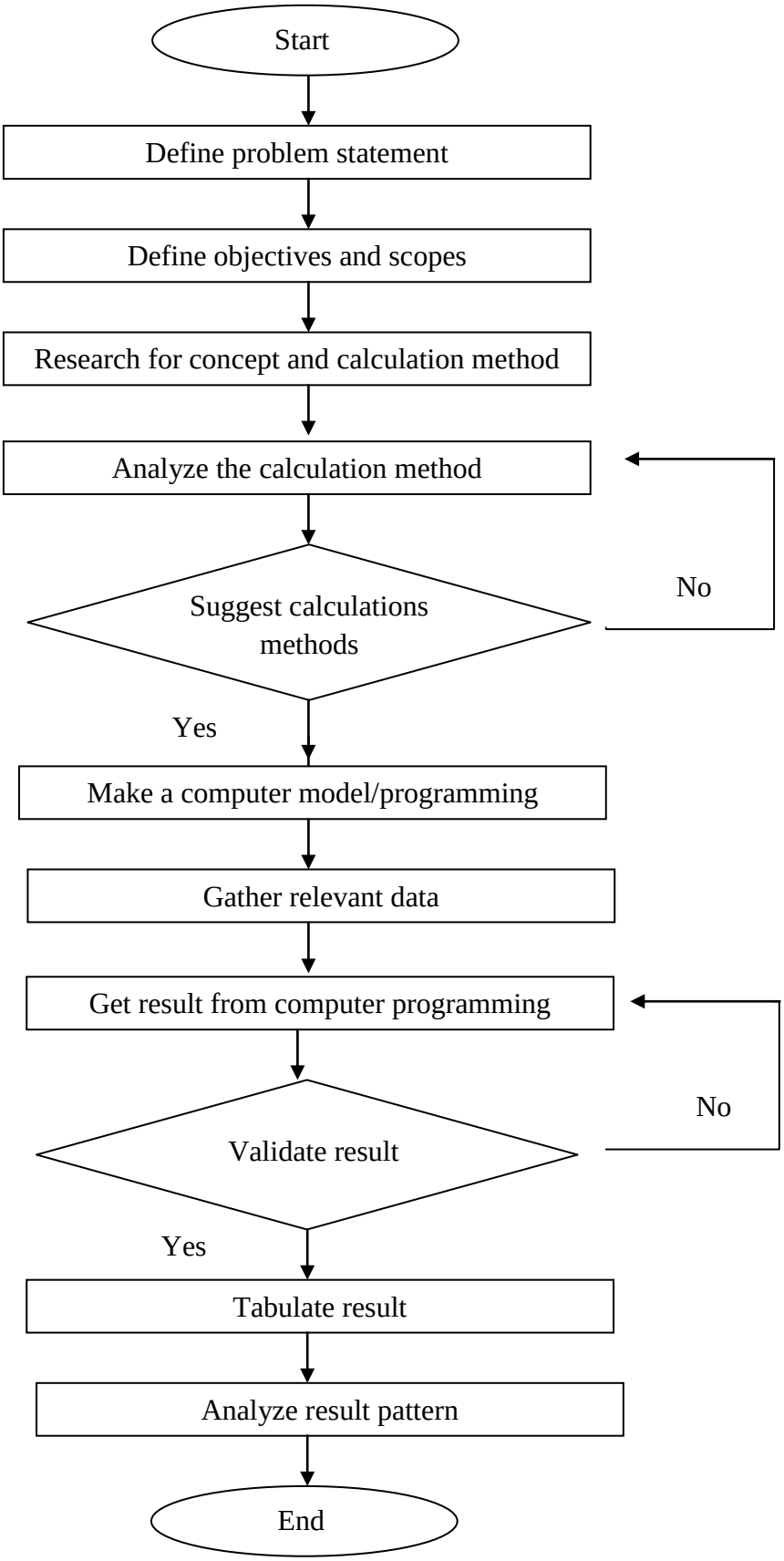

Figure 3.1: Project overall flow chart